Partial Ambiguity Resolution (PAR) for Reliable GPS/Galileo Positioning

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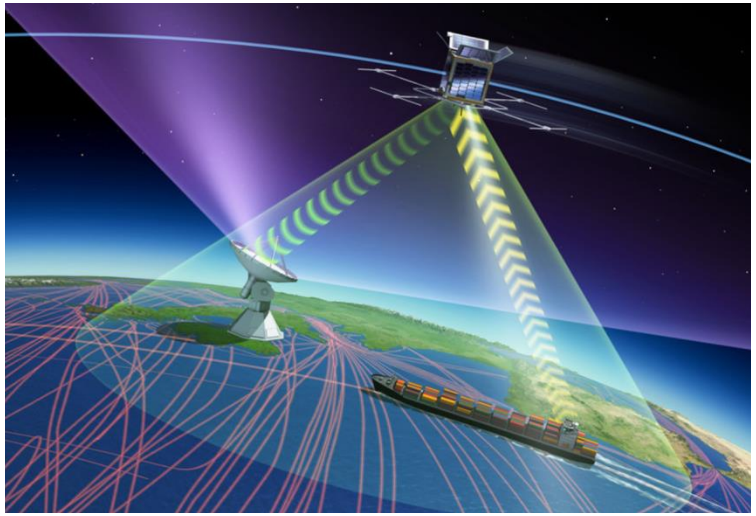
IWGI2019
International Workshop
on GNSS Ionosphere

Outline



source: https://phys.org/news/2017-12-space-technology-autonomous-ships.html

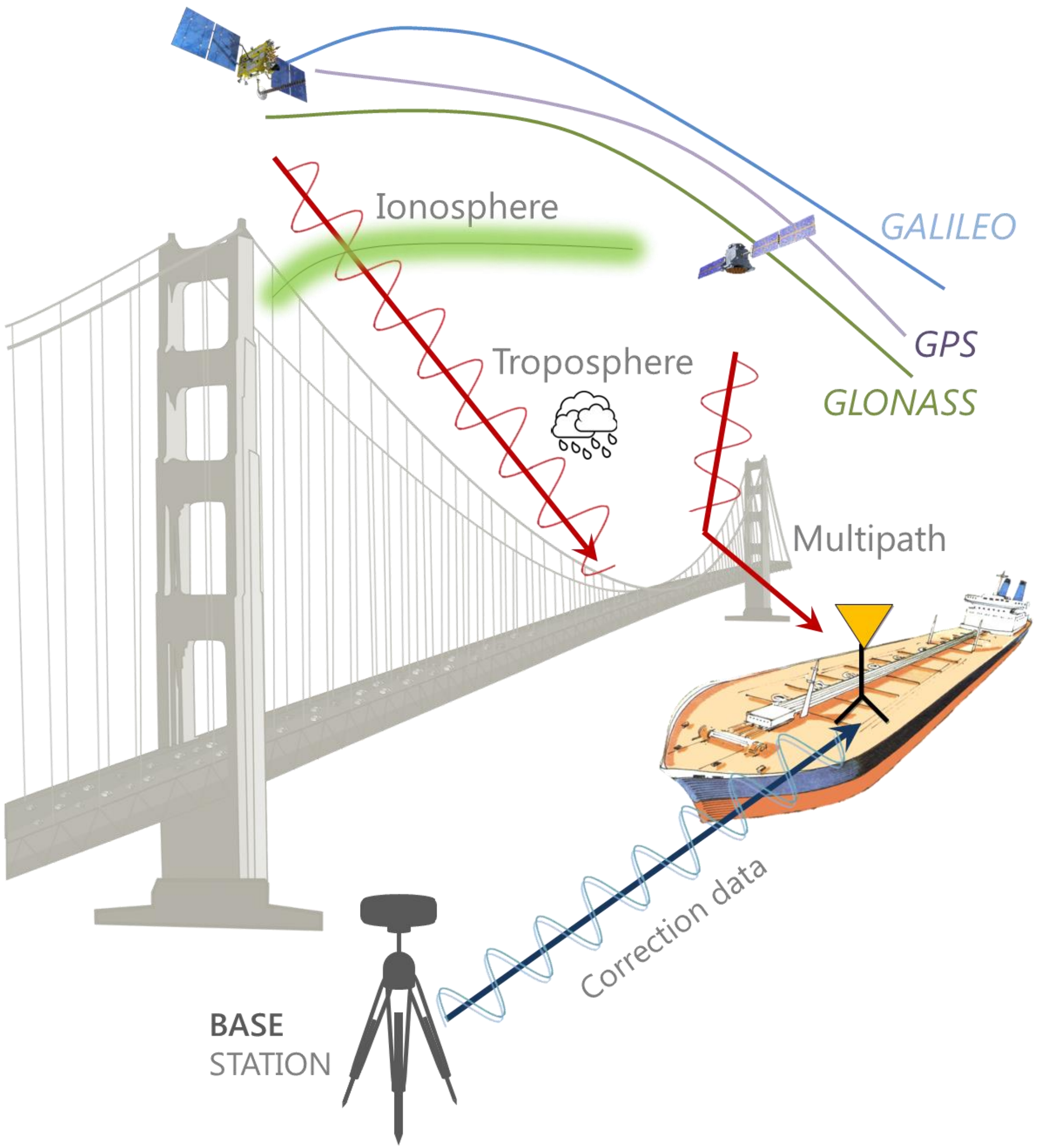
Introduction

High demand for accurate navigation for safety-critical applications

- Automated landing
- Driverless cars
- Autonomous shipping

Precise positioning also in geodesy

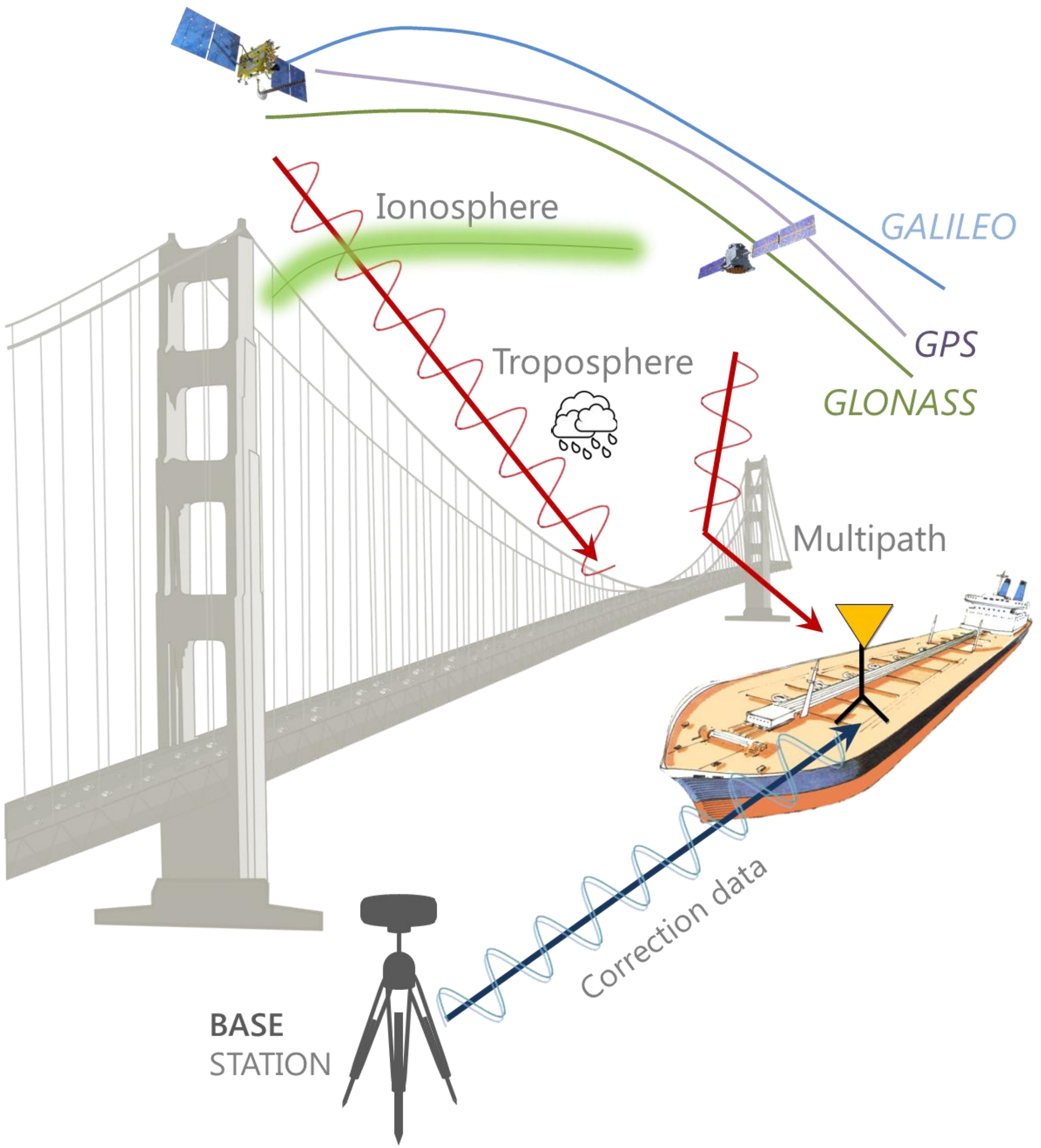
- Geodynamic phenomena (tectonic plate movement, water level, …)



Challenges of Precise Navigation

- Influence of **ionospheric** and **tropospheric** delays
- Ephemeris and satellite clock offset errors
- Mitigate the effect of “*wrong*” observations

- Accurate positioning → use of carrier phase
  - ✓ Very **low** noise
  - ✗ **Ambiguous** by certain number of cycles



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DISCLAIMER:
Radio navigation cares about ionosphere…
About how to remove it!

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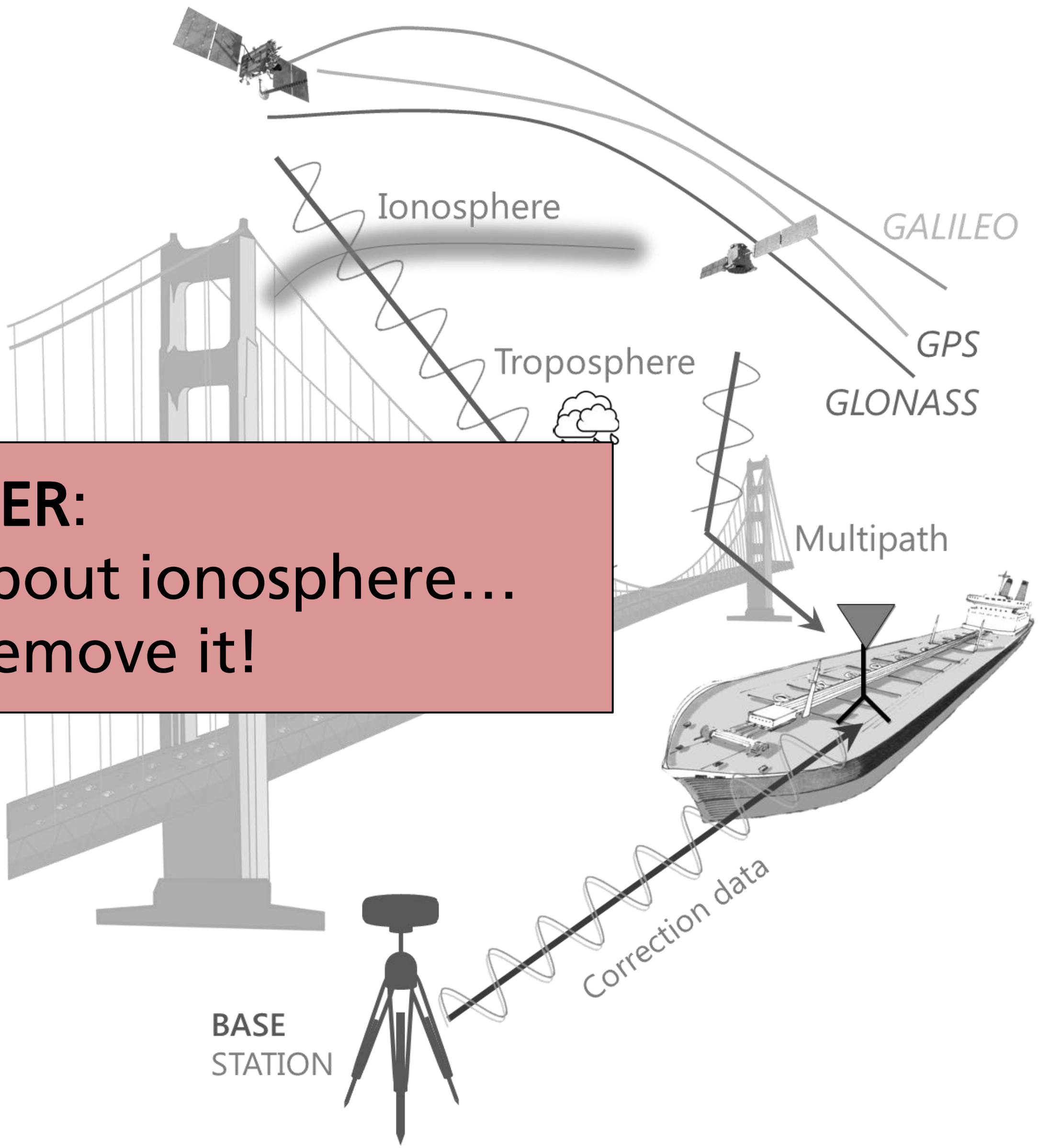

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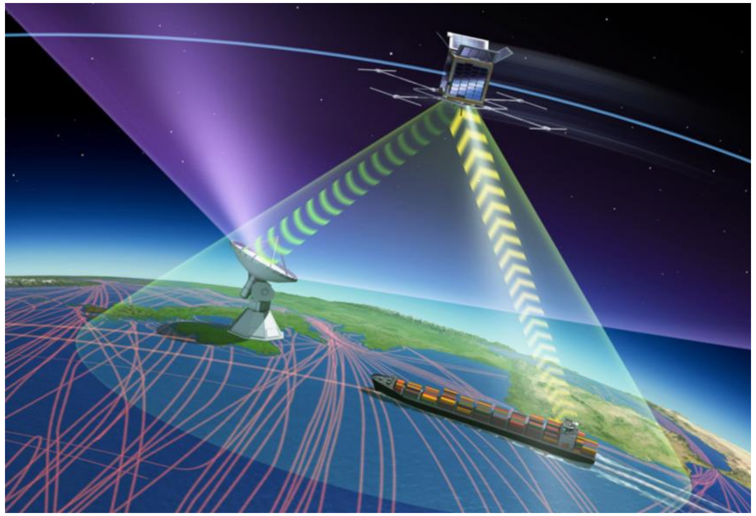

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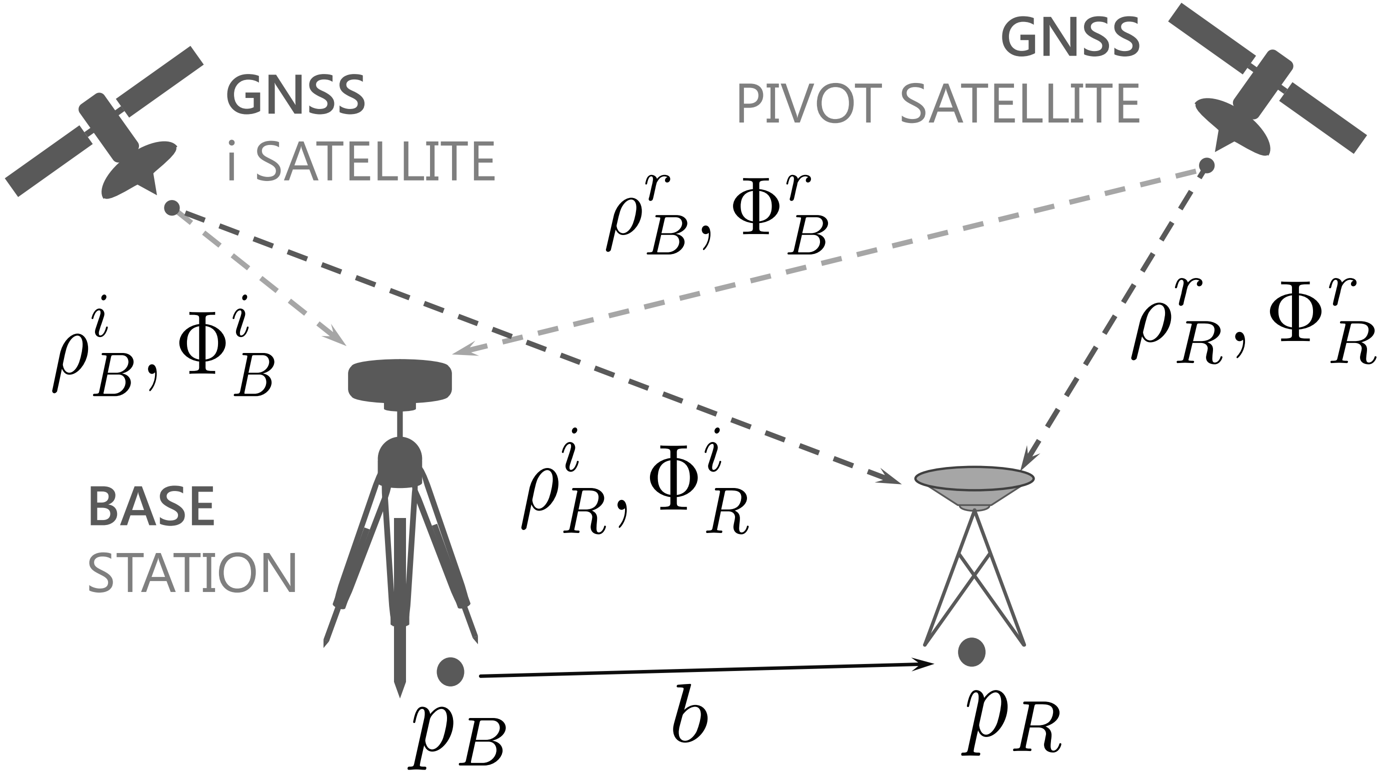
What is Real Time Kinematic – RTK ?



- **Relative positioning method:**
  - A base station of known position required
- ✗ Challenge on correction data link
- ✓ Elimination of satellite- and atmospheric-related errors ***

RTK Positioning Model

$$\Phi_R^i = \|p^i - p_R\| - I^i + T^i + c\left(-dt^i + dt_R\right) + \lambda N_R^i + \varepsilon_R^i$$

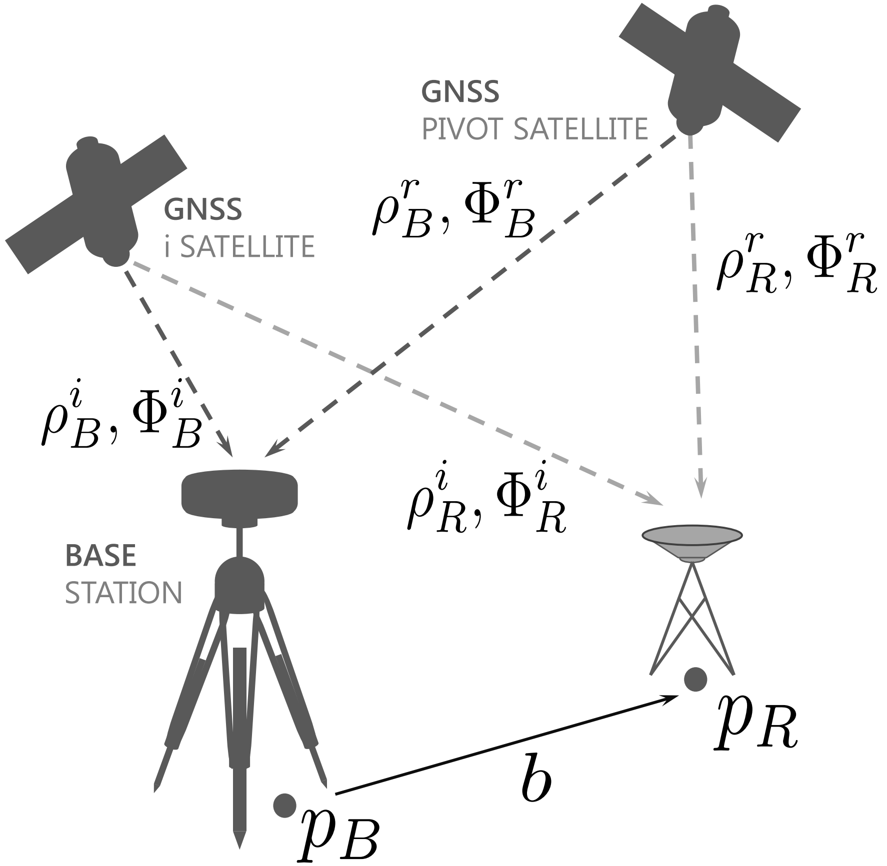
$$(-) \quad \Phi_B^i = \|p^i - p_B\| - I^i + T^i + c\left(-dt^i + dt_B\right) + \lambda N_B^i + \varepsilon_B^i$$

$$\Phi_R^r = \|p^r - p_R\| - I^r + T^r + c\left(-dt^r + dt_R\right) + \lambda N_R^r + \varepsilon_R^r$$

$$(-) \quad \Phi_B^r = \|p^r - p_B\| - I^r + T^r + c\left(-dt^r + dt_B\right) + \lambda N_B^r + \varepsilon_B^r$$

$$DD\Phi^i = -\left(u^i - u^r\right)^\top b + \lambda\, a^i + \varepsilon^{ir}$$

$$DD\rho^i = -\left(u^i - u^r\right)^\top b + \epsilon^{ir}$$



RTK Positioning Model

$$\Phi_R^i = \|p^i - p_R\| - I^i + T^i + c\left(-dt^i + dt_R\right) + \lambda N_R^i + \varepsilon_R^i$$
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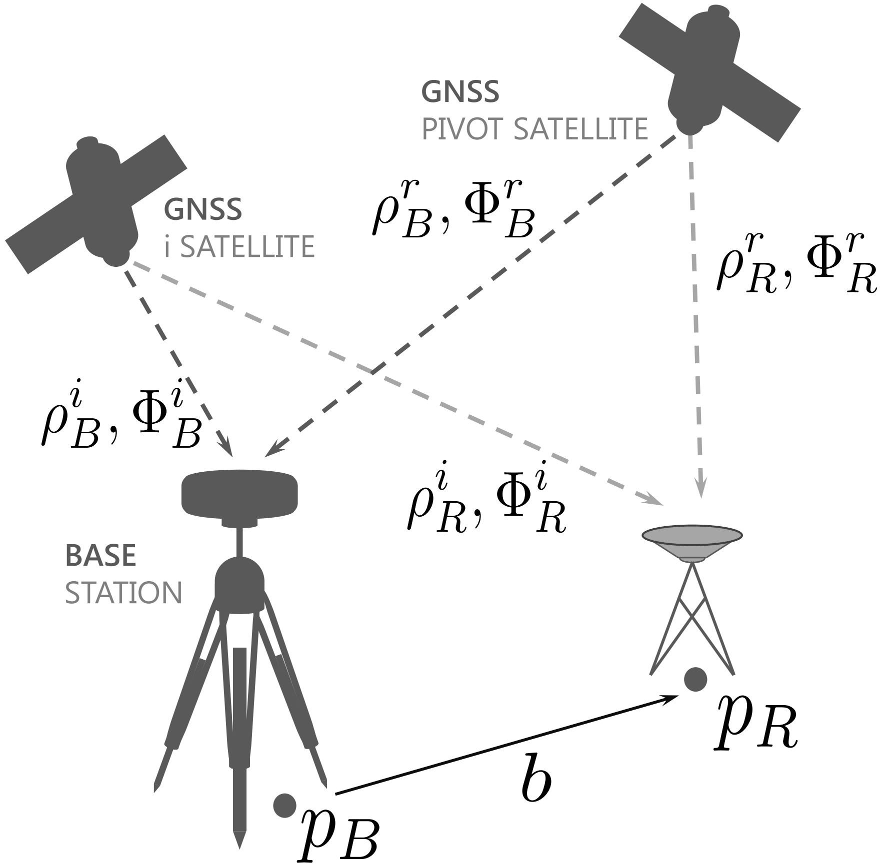
$$(-)\quad \Phi_B^r = \|p^r - p_B\| - I^r + T^r + c\left(-dt^r + dt_B\right) + \lambda N_B^r + \varepsilon_B^r$$

RTK functional model

$$y = \begin{bmatrix} DD\Phi \\ DD\rho \end{bmatrix},$$

$$E(y) = Aa + Bb, D(y) = Q_y$$

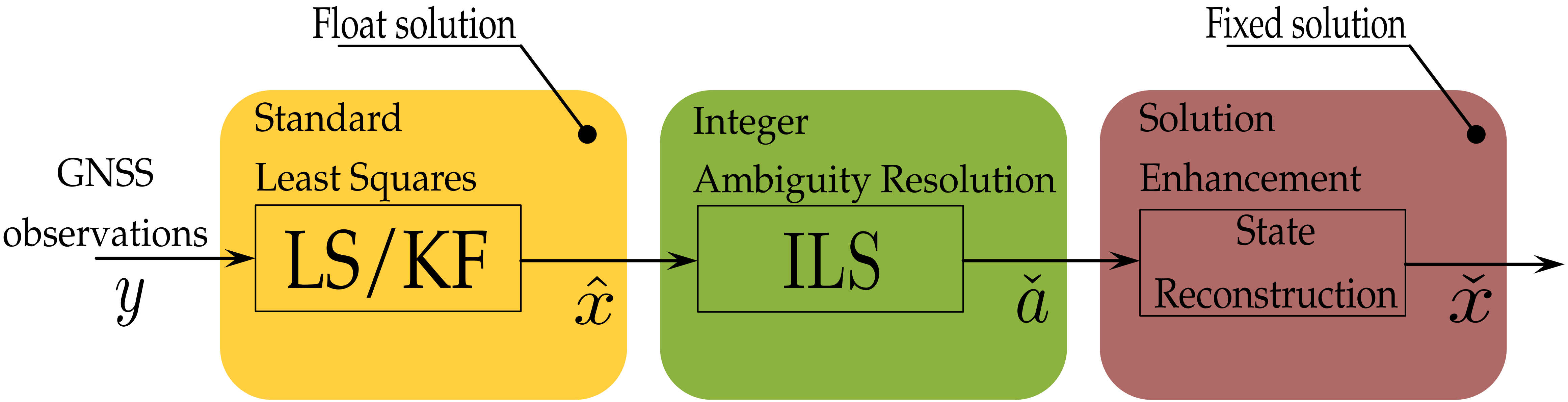


Solving RTK

$$\{a, b\} = \arg \min_{\substack{a \in \mathbb{Z}^n \\ b \in \mathbb{R}^3}} \|y - Aa - Bb\|^2_{Q_y}$$

Solving RTK

$$\{a,b\} = \arg\min_{\substack{a\in\mathbb{Z}^n \\ b\in\mathbb{R}^3}} \|y - Aa - Bb\|^2_{Q_y} = \|\hat{e}\|^2_{Q_y} + \|\hat{a} - a\|^2_{Q_{\hat{a}}} + \|\check{b}(a) - b\|^2_{Q_{\check{b}(a)}}$$

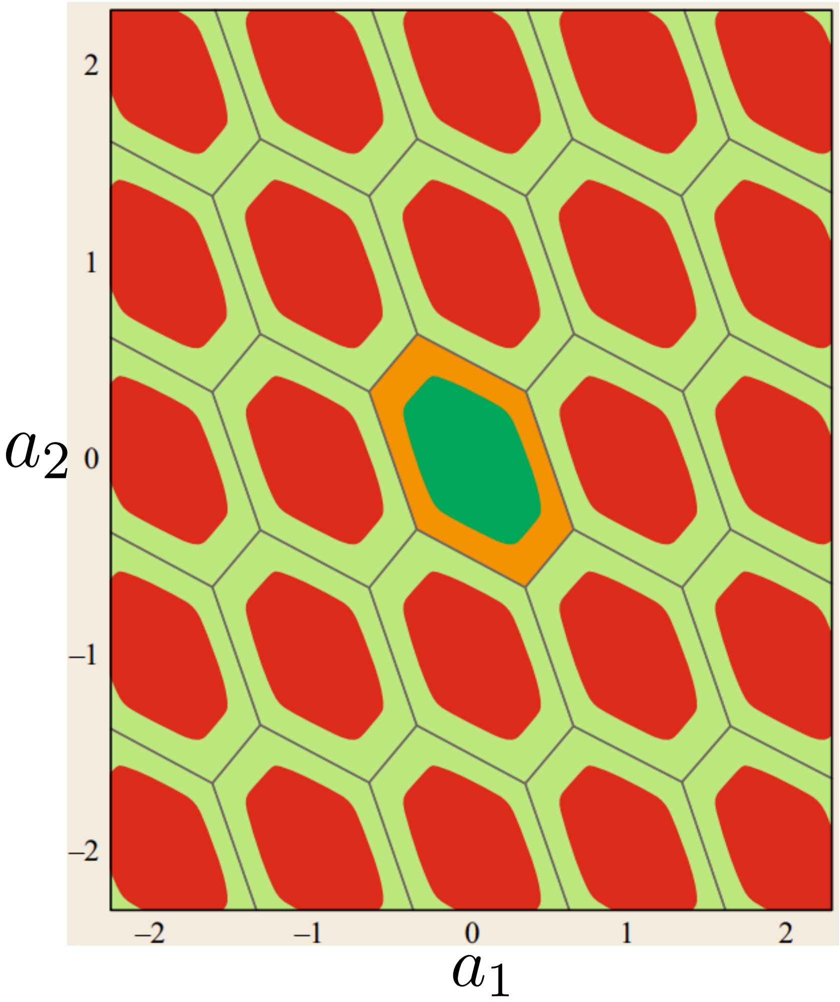


Integer Ambiguity Resolution (IAR)

IAR → process of resolving the unknown carrier ambiguities as integer numbers

- It constitutes a n-hiperdimensional ellipsoidal search
- The success of the process depends on:
  - Quality of the observation model
  - Number of observations

The integer phase → enhance the positioning estimation

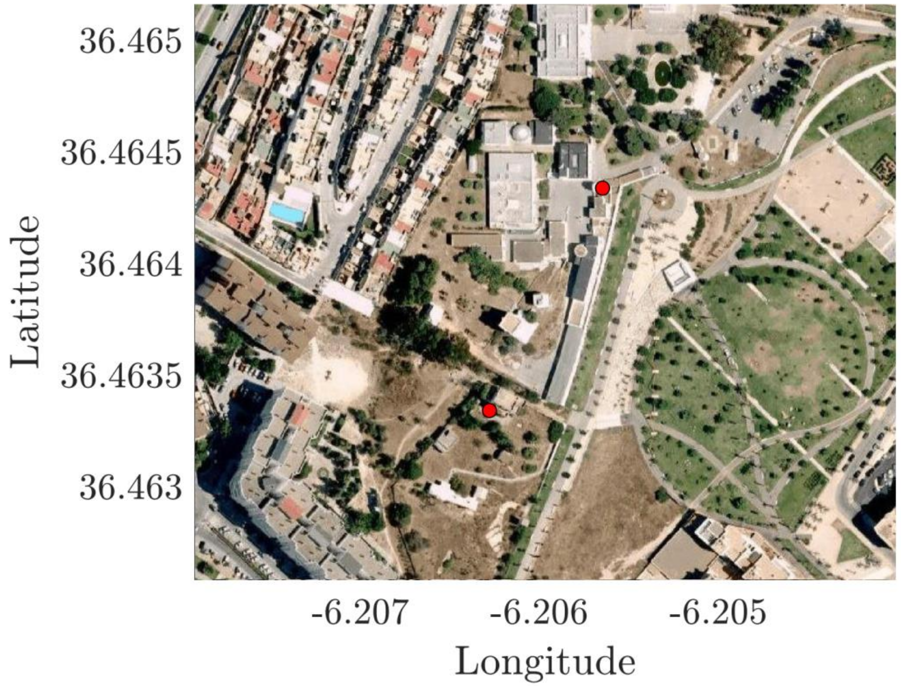


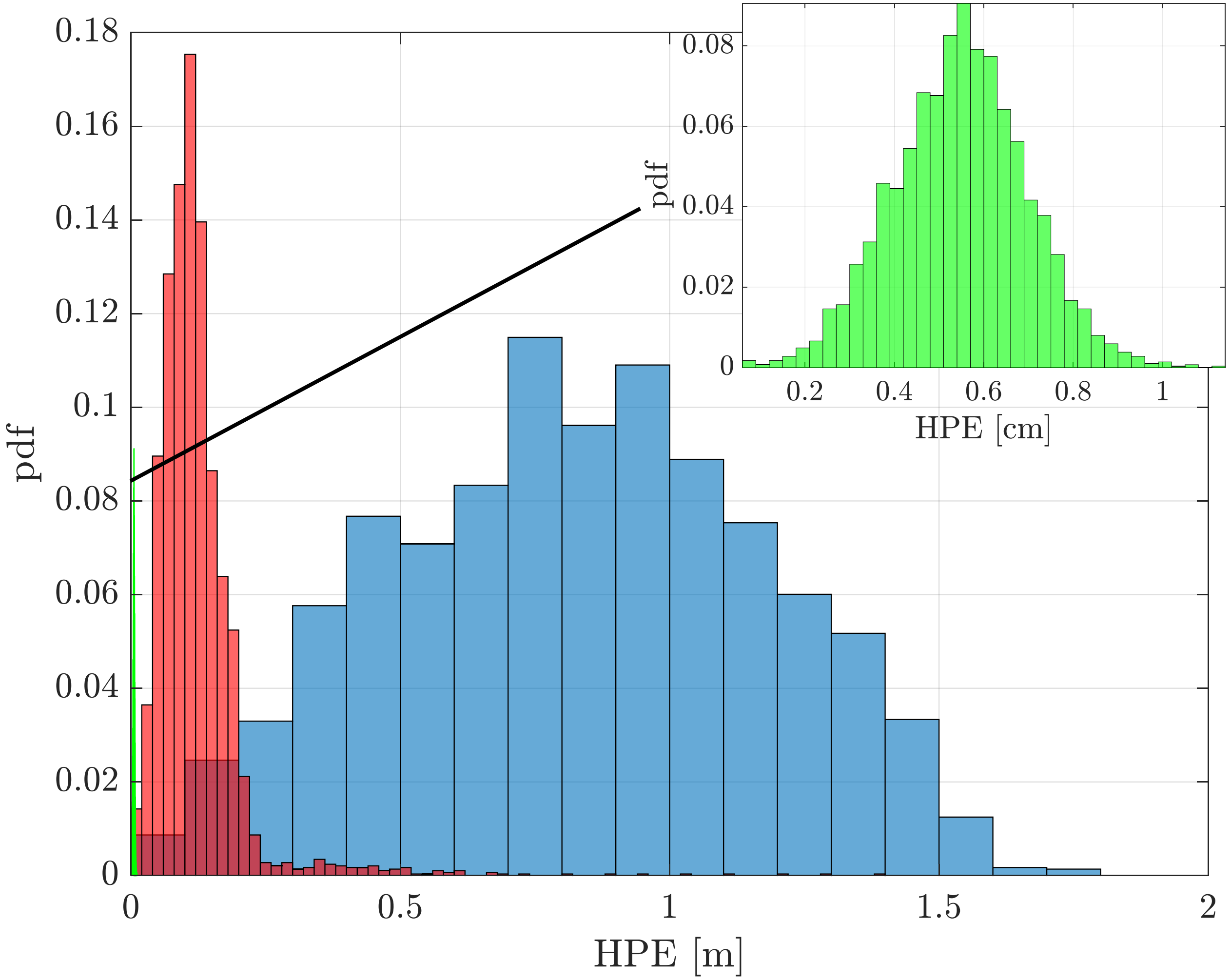
Teunissen, Peter JG. "Least-squares estimation of the integer GPS ambiguities." *Invited lecture, section IV theory and methodology, IAG general meeting, Beijing, China*. 1993.

RTK Positioning: short baseline

San Fernando IGS stations

2019, DOY 001, 00:00 – 23:59





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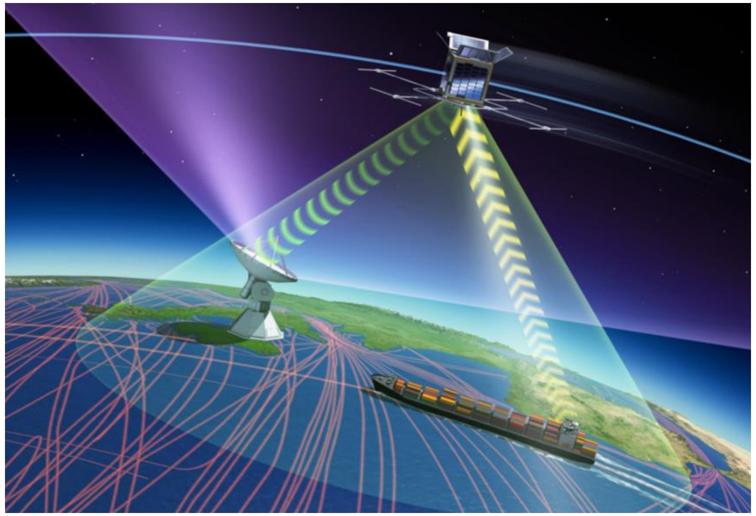

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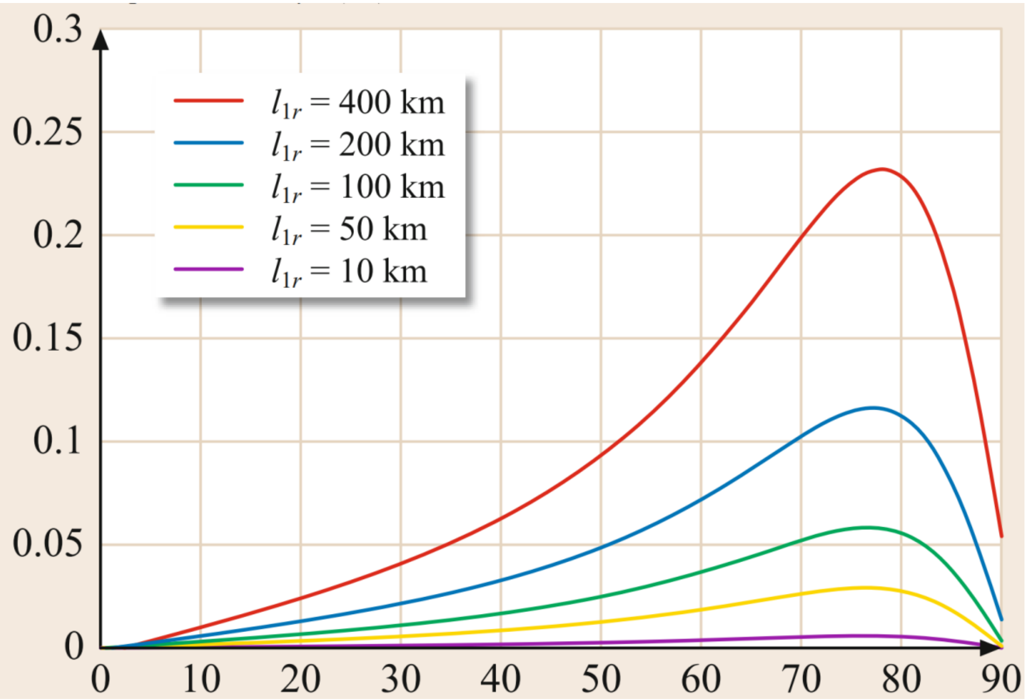
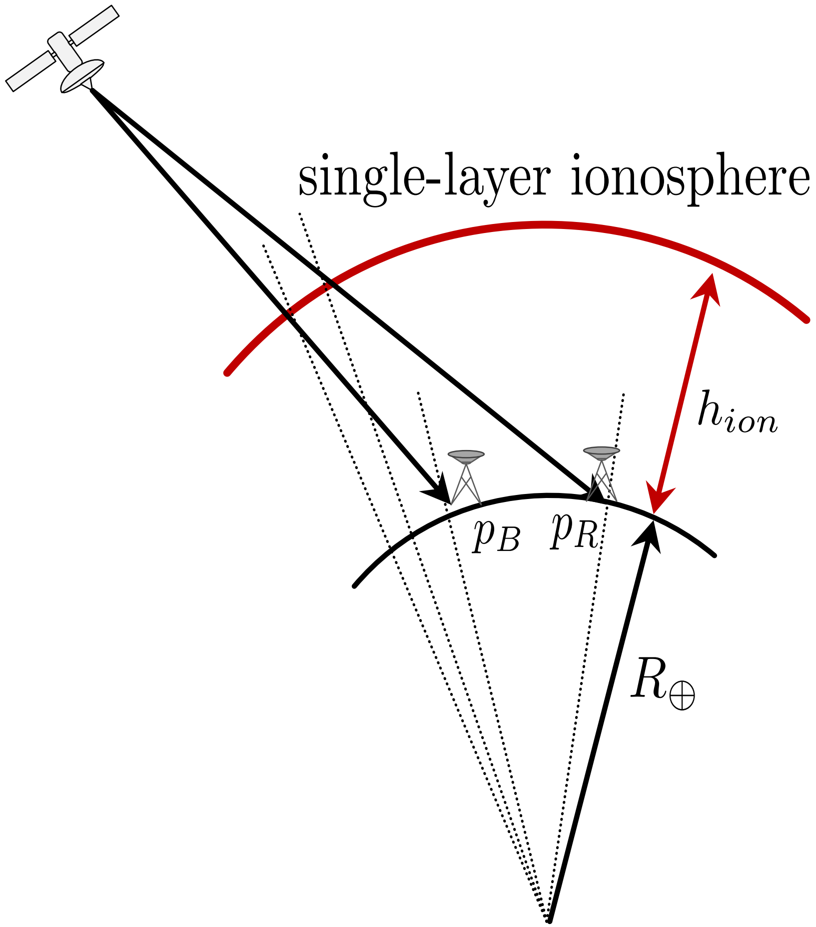
Motivation for PAR

- Based on the baseline separation, ionospheric and tropospheric effects are to be considered

- Dual frequency combination is a bad idea → no IAR

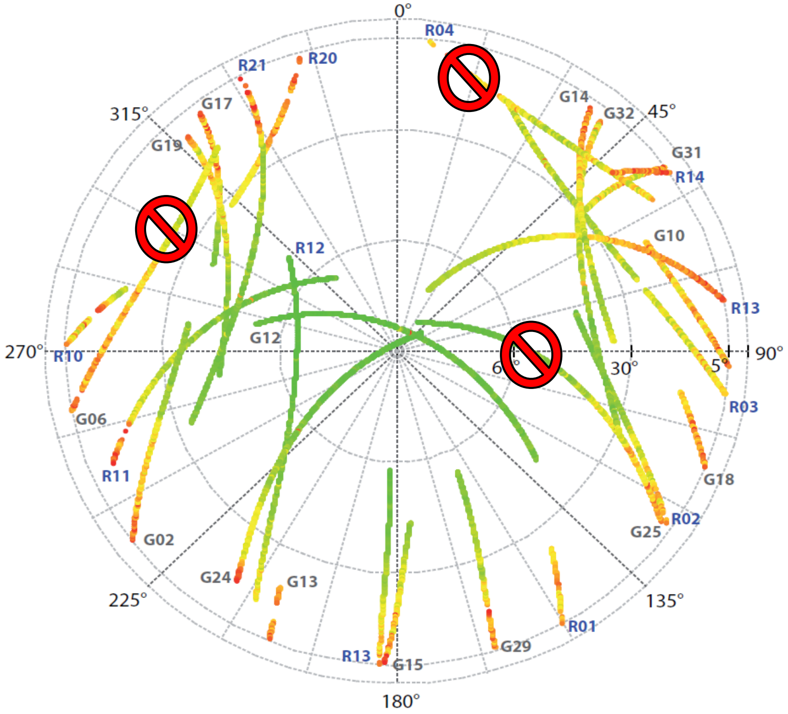




Odijk, Dennis, et al. "On the estimability of parameters in undifferenced, uncombined GN network and PPP-RTK user models by means of S-system theory." *Journal of Geodesy* 90.1 (2016): 15-44.

Partial Ambiguity Resolution (PAR)

- ✘ Regular **F**ull **A**mbiguity **R**esolution (**FAR**) finds (or not) a solution for all satellites
- ✘ The more observations → the more challenging IAR becomes



➢ **PAR aims at:**

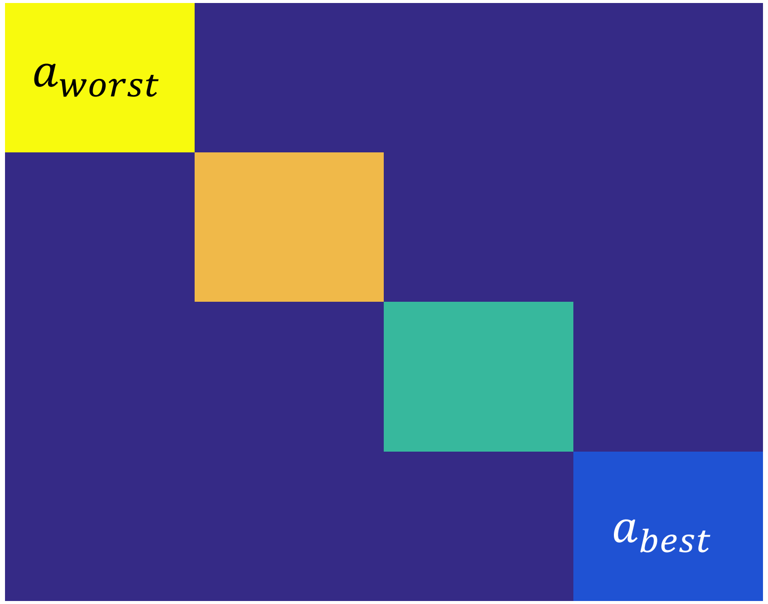
- ✓ Provision of a centimeter-level accuracy
- ✓ Increase the availability of the solution

PAR – Original

- PAR decorrelates the ambiguities and sort them in decreasing noise levels
- Ambiguities are sequentially discarded until a probability of success is fulfilled

✓ Simple implementation

✗ Decorrelation method is affected by biased / contaminated observations



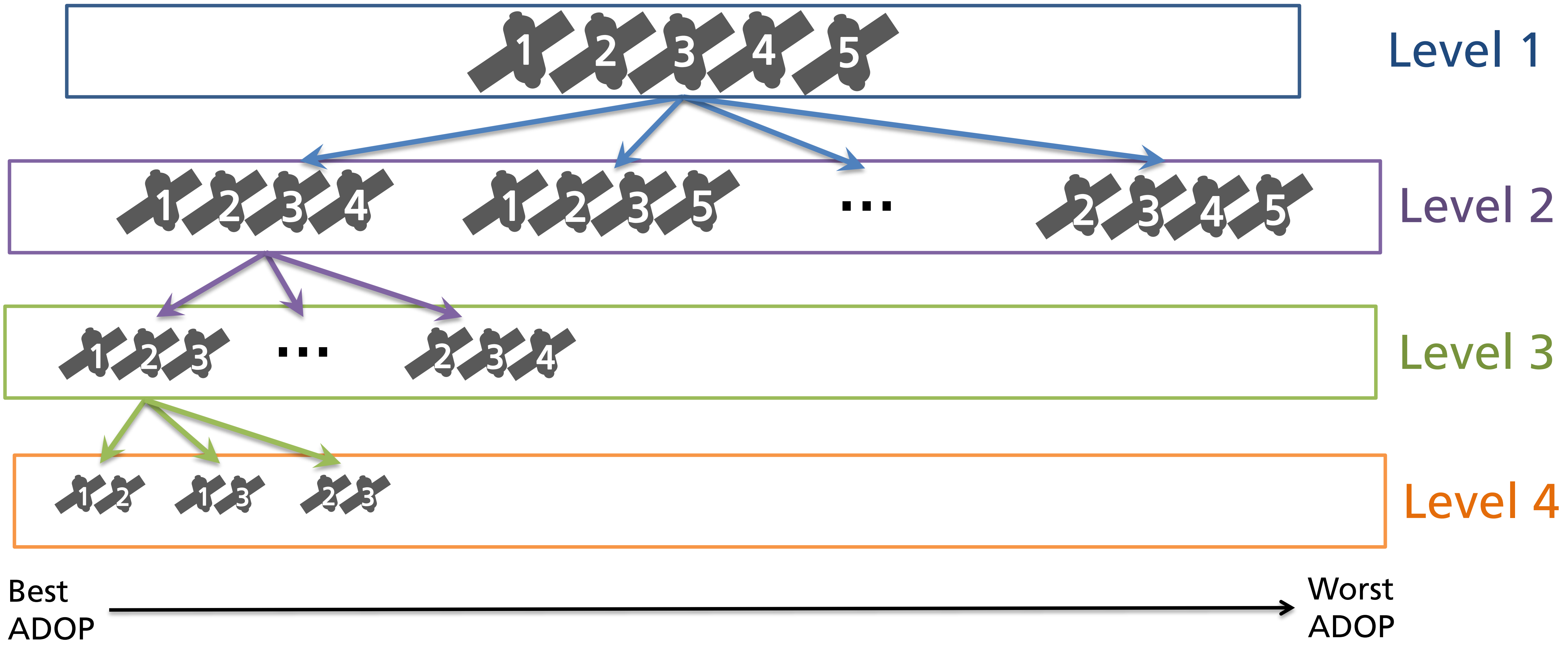
PAR *by Levels*

- Objective function reformulated based on accuracy needed

$$\min \|\bar{a} - \hat{\bar{a}}\|^2_{Q_a}, \text{ s.t. } \begin{bmatrix} \sigma_E \\ \sigma_N \\ \sigma_U \end{bmatrix} \leq \begin{bmatrix} 3\text{cm} \\ 3\text{cm} \\ 5\text{cm} \end{bmatrix}$$

- Set of observations sorted by their Ambiguity Dilution of Precision (ADOP)
- A valid candidate must fulfills:
  - ✓ Probability of successful ambiguity fixing
  - ✓ Minimal (projected) accuracy

PAR *by Levels*



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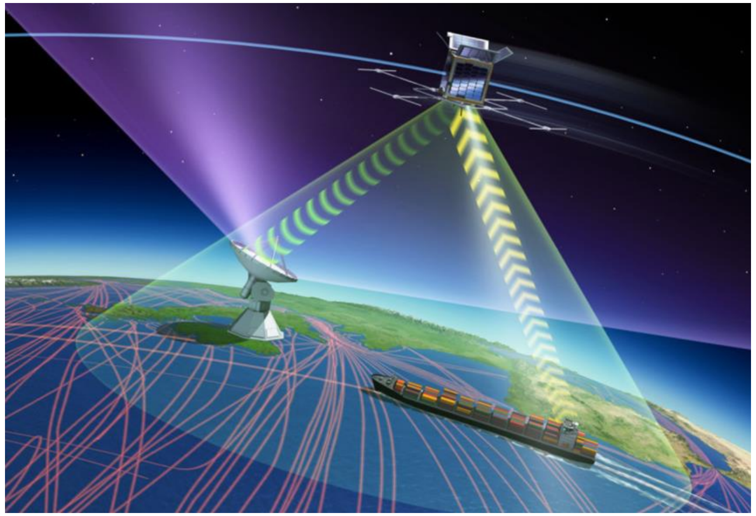

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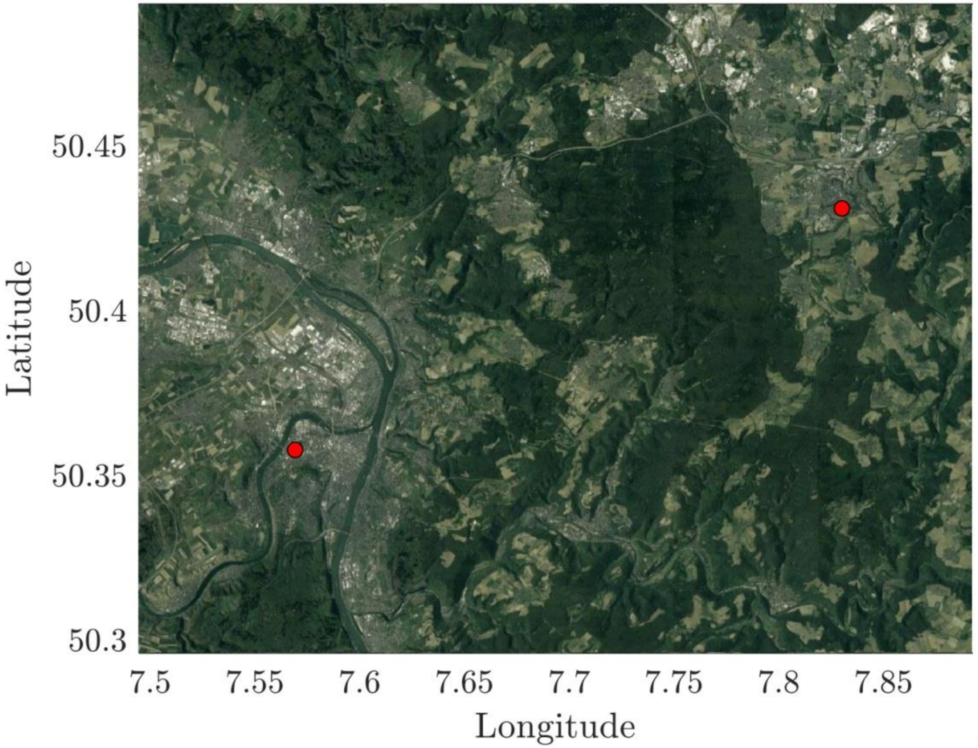
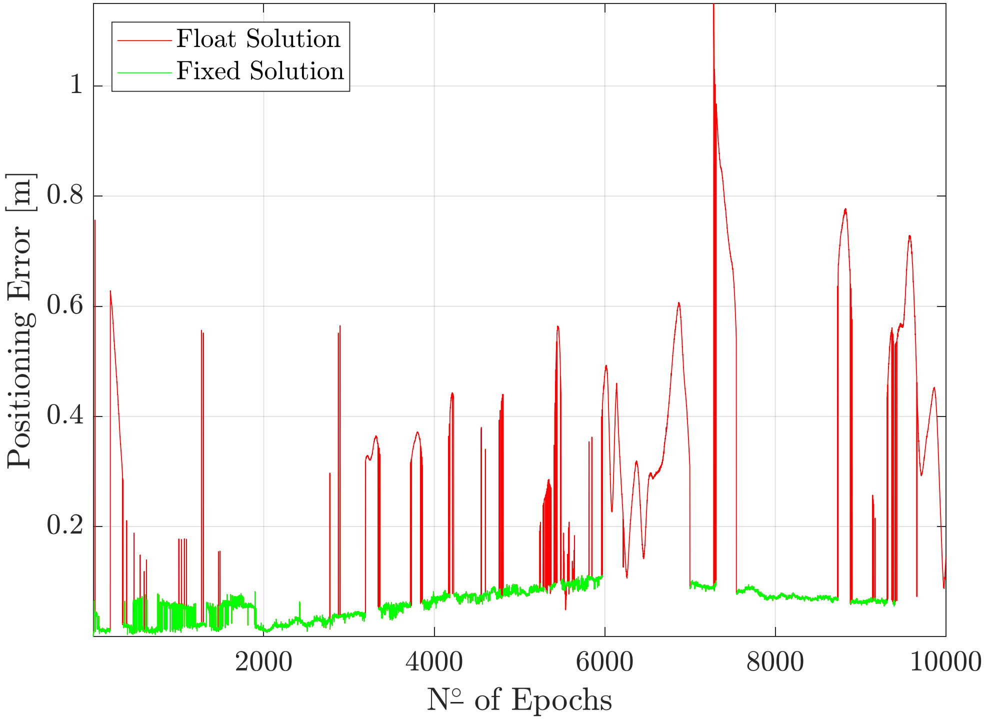
Test and Results: Medium Baseline

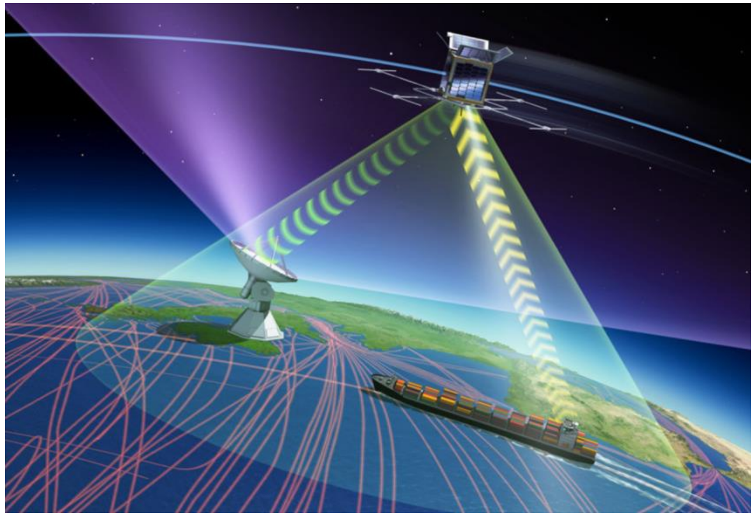
Koblenz – Montabaur Sapos stations (~30 km)
2019, DOY 001, 00:00 – 23:59





Method	**Availability**[%]	**Mean Error** [cm]	**RMSD** [cm]	95% **CDF** [cm]
Float Solution	-	28.17	16.56	62.95
ILS	24.96	7.54	1.12	9.59
PAR – original	30.12	7.94	1.12	11.32
PAR by Levels	78.14	5.9	2.6	9.58

Outline



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Outlook and Future Work

- Introduction to the basics of RTK, the effects of ionosphere in medium/long baselines
- A new PAR methodology is presented, minimal computation for a desired accuracy

- Realize experimentation for long (and very long) baselines
- Is it worth it the addition of ionosphere model to assist on long-baseline RTK?

Thank you for your attention!

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